Final report to the Bay Area Council on Climate Resilience Challenge

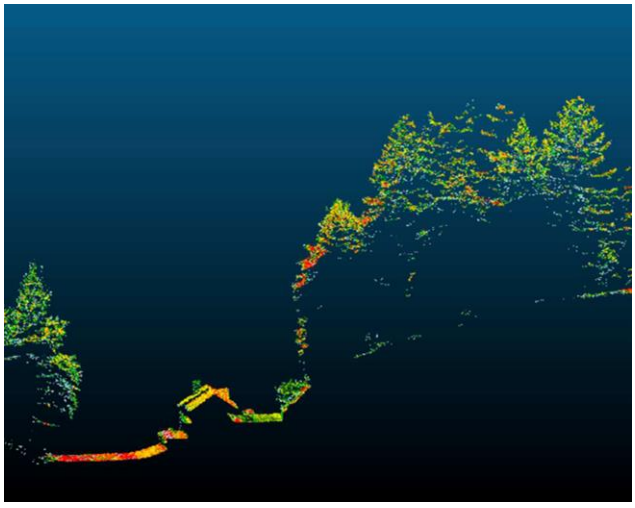
Watershed Research and Training Center

Summary

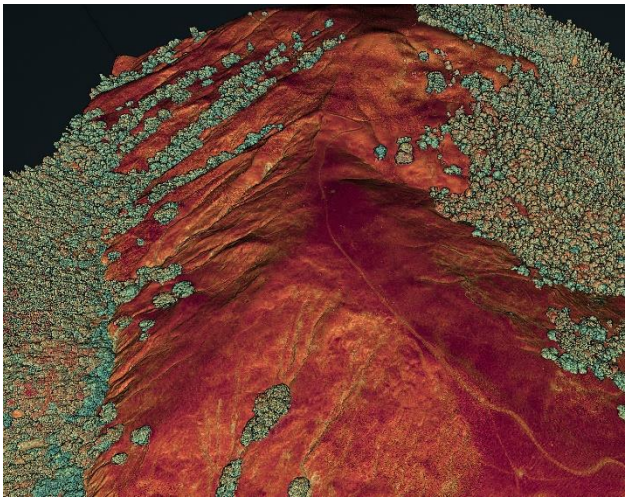
The California Forest Lidar Analytics was established to develop community infrastructure to deploy lidar analytics in the planning and implementation of the States forest climate resilience challenges.

This involved:

- Providing professional technical training in the use of the open source lidar analytics for a user community that is already involved in forest and watershed restoration.
- Providing technical support for climate resilience projects during the development phase of funding proposals
- Applying Agile and user centered design strategies to develop user centered reference implementations.
- Facilitating access to high performance computing assets through our partners.
- Participating in State lidar policy mechanisms to facilitate acquisition and development of foundational spatial data infrastructure.



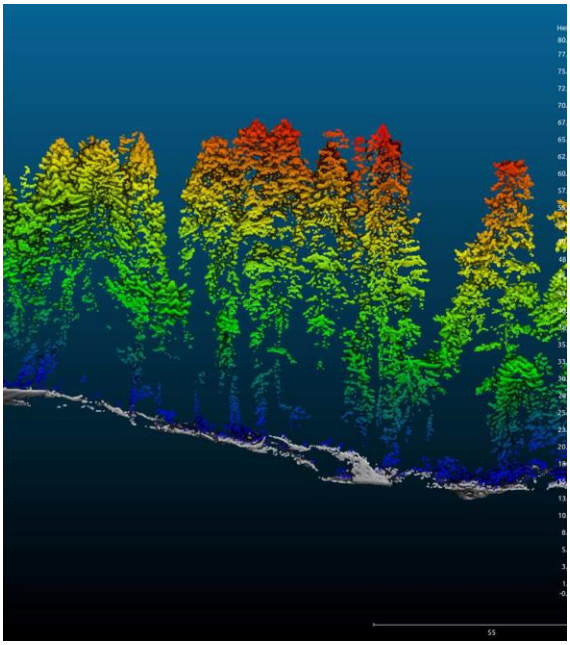
Background



California has committed unprecedented resources to forest climate resilience. Through the Forest and Wildfire Taskforce the State and Federal governments have committed to dramatically accelerated treatments to enhance forest resilience. As these implementation resources are being deployed there is a growing need to monitor and demonstrate the effectiveness of these efforts. Airborne Lidar data plays a critical role in this

The political economy evolving to meet these challenges is a complex federated system of agencies with specific mandates and many third-party implementation partners that implement them. These are composed of nonprofits, local agencies, tribal governments, and resource conservation districts. In addition, there is an intention to create an open natural resources information ecosystem that can allow commercial contractors, and private parties transparent access and participation in natural resource decision processes. Geospatial information systems have become an essential mechanism for exchanging information between these organizations.

Airborne Lidar has emerged as a uniquely effective tool for assessing the condition of forest structure. Most forest fire and drought susceptibility characteristics are structural in nature. Spectral remote sensing systems such as Landsat and NAIP simply do not capture the core dynamics indicative of forest climate resilience conditions. In some cases, treatments like shaded fuel breaks or under canopy burns are not even detectable by spectral remote sensing.



While Lidar derived forest practices have been a core strategy in precision forestry and in commercial carbon offset forestry approaches for more than a decade, these practices have not been picked up by the public interest forestry sector that is implementing California's forest climate resilience strategy.

The California Forest Lidar Analytics Collaborative was developed to support technical adoption of lidar derived analytics by the community of practice. In many cases organizations would recruit technical skills from external sources. While this is a necessary strategy, we also see a need for training a user community that is already invested in forest climate resilience work. As we look to the workforce capacity challenges we need to upskill our existing workforce as well as bring in new workers.

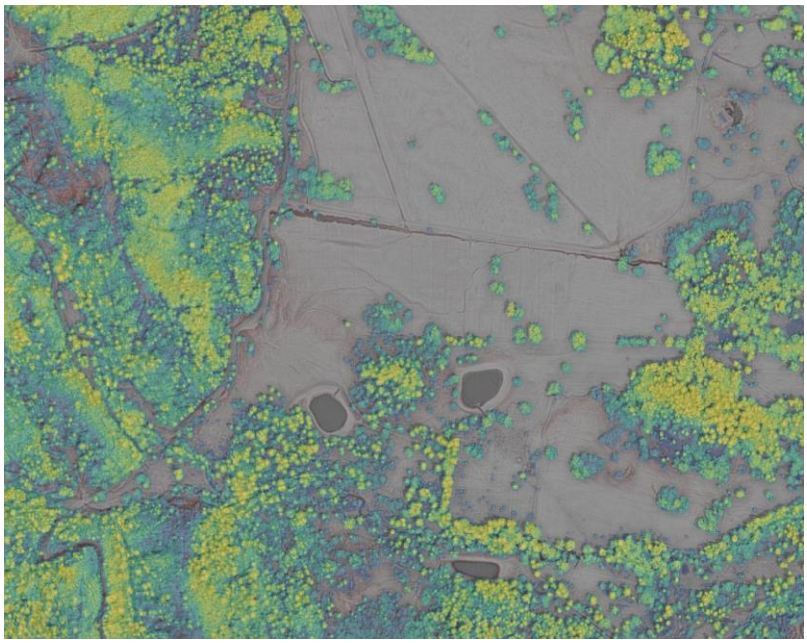
We have adopted best data management practices that are increasingly prevalent in academic research. The core concepts have been distilled as FAIR data science, Findable Accessible, Interoperable, Reproducibl. Through this process we have also increasingly recognized the need to incorporate CARE principles. This is particularly true of data that could have implications for

Coordination

CaFLAC played an instrumental role in representing spatial data users within the climate resilience project developer community in the USGS Broad Area Announcement. CaFLAC and our collaborators at the North Coast Resource Partnership were persistent in demonstrating the value of watershed wide lidar coverages and expressing the needs of the natural resources community.

Public presentations

In the first year of CaFLAC 1600 unique individuals participated in one of the public presentations including at the American Geophysical Union, the FOSS4G geospatial software conference, six different Forest Management Taskforce committees, Several Regional Geo Spatial User Group meeting. There was extensive outreach through networks such as the Fire Adapted Communities Network and the Regional Forest and Fire Capacity program.



Training

Caflac held two training sessions with 18 participants in 2021 spanning 10 weeks each. In total 65 people applied to take part in the workshops. Participants were selected competitively. Preference was given to participants that had a clear nexus with forest health project proposals. These included employees from the USFS, Calfire, Department of Conservation, 3 Resource Conservation Districts, two watershed councils Every week we held 1 hour of prepared lectures and demonstration and then an hour discussion to explore common issues, work through code and Through this training we developed user story narratives and identified barriers to deployment of this technology. The core analytical and processing tools were the R package LidR, and PDAL, the Pointcloud Data Abstraction Library. There were a number of other tools like cloudcompare and grass that were demonstrated. Participants developed geospatial data products that served their organizations goals

Funded Project Proposals with technical support from CaFLAC

CaFLAC has provided direct technical support to many project proposals during the development phase. In each of these cases CaFLAC developed advanced geospatial products using Bay Area Council California Resilience Challenge funding during the project scoping phase. Where feasible these are reference implementations that are representative of widespread planning needs.

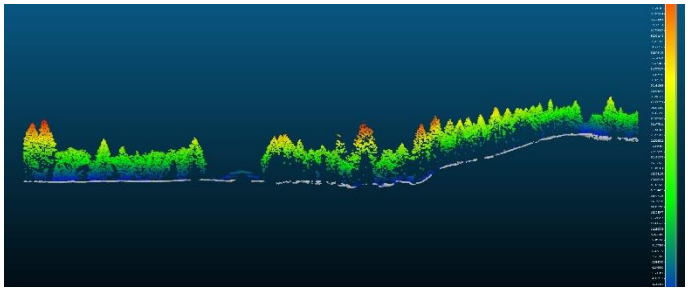
Project	Funding awarded	Description
2022 USGS Northern California 3DEP Lidar BAA	**$7 m**	The single most important product to come out of the BAC funding of CAFLAC has been the successful Northern California US Geological Survey Broad Area Authority proposal. In association with the North Coast Resource Partnership, CAFLC developed a successful $7 million dollar 50 thousand sq kilometer US Geological Survey Quality Level 1 Lidar acquisition. Primary collection was completed in November 2022 with full publication scheduled for July 2024. The USGS solicitation process had not been easy for rural communities to participate in. California's large urban and mid-sized counties had previously been able to develop and fund lidar acquisition proposals that provided necessary match for federal programs. Once finally published this will complete first lidar coverage for 13 Counites in Northern California. In addition we laid the ground work for 2023 collections of fire affected landscapes across the Coast Range in Mendocino, Lake, Trinity, Glenn and Tehama Counties.
2022 Yurok Tribal Fisheries Department of Commerce economic development grant	**$5m**	The Yurok Tribal Government fisheries departments construction program has been a technical leader in using point cloud technologies for more than a decade. With the advent of the Klamath Dam removal projects the need for state of the art point cloud technology was clear. In 2018 they were instrumental in a USGS lidar collection on the mainstem of the Klamath River. The Yurok tribe has positioned itself as primary remote sensing contractors for the Klamath Dam removal. CaFLAC supported development of the technical strategy and supported the Department of Commerce application. In addition the Yurok were awarded a portion of the Northern California 3DEP covering their ancestral territory.
2022 Klamath Basin Post fire mutual aid agreement	**$11 m**	In the Summer of 2022 the Yurok Tribe and CaFLAC were able to get a 10 billion point photogrammetric point cloud over 90,000 acres flown 18 days after catastrophic debris flows on the McKinney Fire in Siskiyou County. This area was reflown in the Summer of 2023 with the Yurok Tribes new lidar instrument. This is a unique dataset recording an extreme post fire sediment event before and after the first winter and will be instrumental in the Post fire recovery work. This project was awarded $1.5 million in an Integrated Water Resource planning grant and $9 million from CDFW's Salmon Climate emergency funding for post fire fisheries restoration for regional implementation partners including the Yurok Tribe, the Karuk Tribe, MidKlamath Watershed Council and Watershed Research and Training Center.
Northern Mendocino Forest Health Collaborative.	**$4.5 m**	Working with the Redwood Forest Foundation and Arcata BLM, CaFLAC developed single tree inventories of proposed treatment areas that were included in a 2021 Forest Health award the early dataset was particularly important for the fuel break near the Northern terminus of Highway 1. Development of the treatment and access plan was especially important because it reduced the traffic control issues during implementation.

Sonoma State University Calfire Forest Health Research Grant	**$500k**	This project involves validation and operationalization of data from the GEDI full wave form lidar system on the International Space Station for statewide forest canopy change detection between 2019 and 2022. WRTC coauthors
Ten Mile Creek Forest Health assessment pilot project	**$140k**	Developed 15 forest management plans in the Ten Mile Creek Watershed. For each parcel lidar derived tree inventories were developed and provided to the landowners and the foresters developing the plans.
Tenmile Creek Watershed Forest Health implementation Plan	**$5.9 m**	Building on the community outreach from the NCRP pilot project a large environmental compliance and implementation plan was developed in a critical coho watershed near the source of the South Fork Eel River in Mendocino County. This was particularly innovative because it included a record number of small nonindustrial forest landowners in a Forest Health proposal.
Upper Trinity Wildfire Resilience Planning Grant	**$1.5m**	In 2022 the Sierra Nevada Conservancy invested in a planning proposal that included a significant investment in geospatial planning infrastructure. This included a watershed wide lidar derived tree census and the second USGS 3DHP compliant elevation derived hydrography coverage in California. This is arguably, one of the leading geospatial forest and watershed planning initiatives in the State.
Klamath Meadows Partnership	**$1.5m**	The Klamath Meadows Partnership is a consortium of 20 NGO's, tribal governments, agencies and Universities working on meadow restoration in the Klamath, Cascades and Coast Ranges. Lidar hydrologic assessments and landform analysis is a critical component of the regional prioritization strategy.
Humboldt Bay Municipal Watershed Forest Health Watershed recovery plan	**$5m**	Cross boundary post fire recovery proposal in the Mad River Watershed, which is the source for the Humboldt Bay Municipal Water District and was severely affected by the August complex in 2020
Total	**$46.5m**	

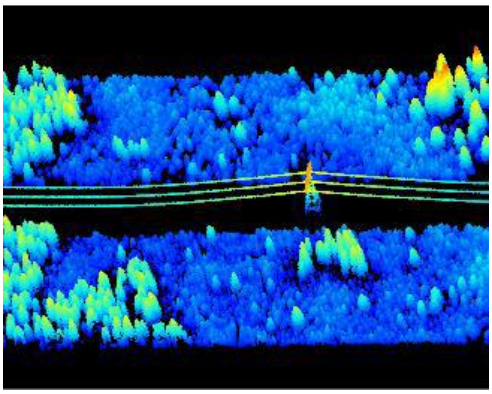
Lessons learned.

The largest project done by participants in CAFLC programs outside of WRTC was a single tree inventory of a 790 sq km watershed in Humboldt County. There were two ownership wide single tree inventories of approximately 200 sq km each for public interest forestry projects. Within WRTC we developed a 2000 sq km single tree inventory, a hydrologic inventory of the same watershed and road network extraction among a range of other lidar derived products.

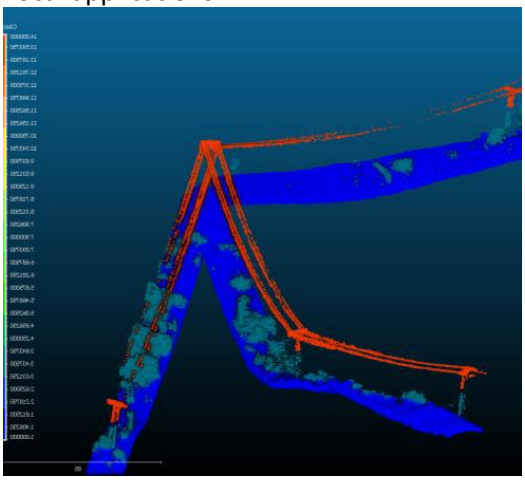
Many of CAFLC's early assumptions about efficiencies using Cloud resources may not be as compelling as we initially believed. With a little foresight, these projects are very achievable with current generation consumer grade equipment. In most use cases that we worked with users elected to migrate to local resources at the end of our support.



The scaling issues are much more pronounced for enterprise users at agencies. For example, if you have a 800 sq km Forest Service Ranger District with a USGS QL1 lidar coverage your primary point cloud could be 250 gb. Individually this is manageable with consumer grade storage solutions. If you have ten advanced geospatial users accessing the point cloud and creating individual copies the storage costs will ramp up dramatically. There are other structural concerns with this approach to file management.



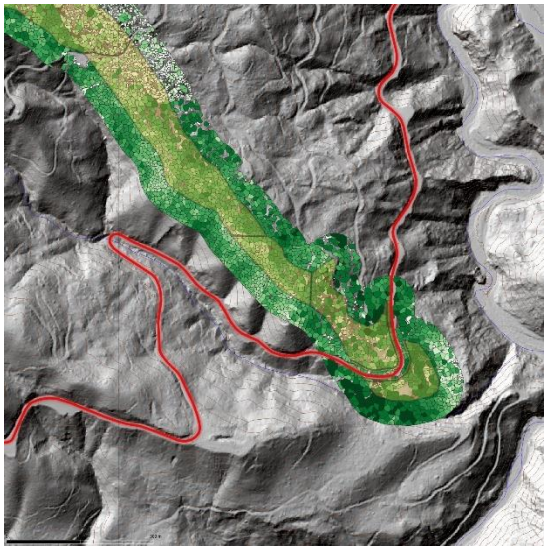
The hybrid cloud strategy selected is extremely sensitive to internet capacity. Internet bandwidth issues are highly variable across the State. In California's urban and suburban areas there is often high-speed internet that can easily stream Point Cloud datasets directly from the USGS Amazon or other cloud services. At the hypothetical remote USFS office they could have many advanced users sharing quite limited bandwidth. One telling sign is when you have more than 3 employees of an organization clustered around a single computer for a conference call. In these cases, a variety of hybrid cloud solutions will outperform both pure cloud based and local applications.



It is also easy to see computational and storage resource demands growing at a rapid pace. WRTC developed several terabyte scale photogrammetry projects. In one case 2 cm resolution orthoimagery for a 12 square km proposed treatment area, the primary photogrammetric point cloud, orthophotos and raw data resulted in a 1.4 terabyte archive. Similarly for a UAV lidar scan of a powerline network the raw data was coming in at over 100 gb per km of length. There are several other technologies that are becoming operationally relevant that will require significant computational resource demands. The cloud data management strategies are going to continue to be relevant to lower depreciating equipment costs and avoid paying for equipment that can manage the single highest computational load.

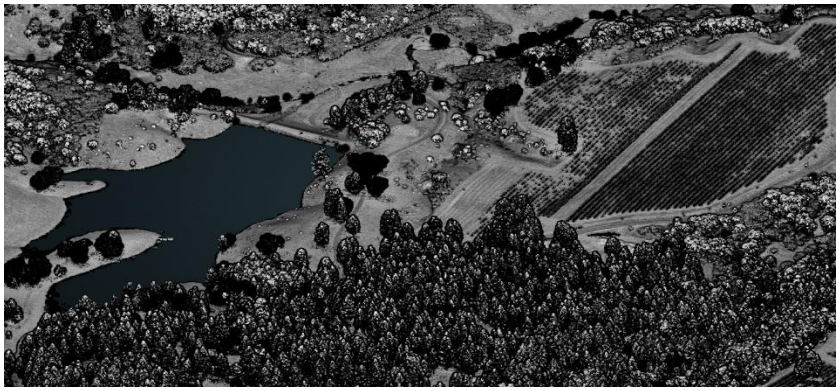
Our assessment is that enterprise geospatial users have some of the highest returns for investments implementing FAIR best data management practices. Thus far agencies only have limited ability to implement these practices. Unfortunately, we see that the enterprise investment in commercial software acts to reinforce idiosyncratic file management systems by individuals at the agencies. These practices result in several systemic inefficiencies. These patterns were on display in a project to populate a county wide geospatial infrastructure system using internal Forest Service data products.

There is a tension between rigid rules and user freedom. Often enterprise systems are not developing the quality of metadata necessary for open exchange of the data. This has been understood at the federal level for a very long time. Subject area data stewards often hold personal file copies of datasets which are shared through personal requests. This pattern is subject to significant disruptions due to personnel changes and represents significant institutional liabilities. While there are needs to manage sensitive datasets such as cultural resource records, personal information and sensitive species, this data management pattern only achieves this by denying access.



Within the agencies there are often individual users that have personally adopted FAIR practices but this is a minority of users. Several researchers at the USFS Pacific Southwest Research Station have migrated best data management practices from academic settings to their current work at the Forest Service. There is a significant generational component to this. Younger data stewards who worked with cloud computing assets in academic settings are much more likely to be familiar with the range of tools that support FAIR data management.

One of the user stories that we think is most compelling is for small nonindustrial forest landowners to extract ownership wide coverages and develop single tree inventories from ldiar. A reference implementation of this user story vignette was developed in a 2020 NCRP demonstration pilot in Ten Mile Creek in Mendocino County. In this project forest management plans for 15 parcels were coproduced with the landowners. Cartographic and analytical materials were extremely useful to the landowners considering their options. Getting a reliable quantity and size distribution of trees allowed them to make difficult decisions balancing risk and tree retention.

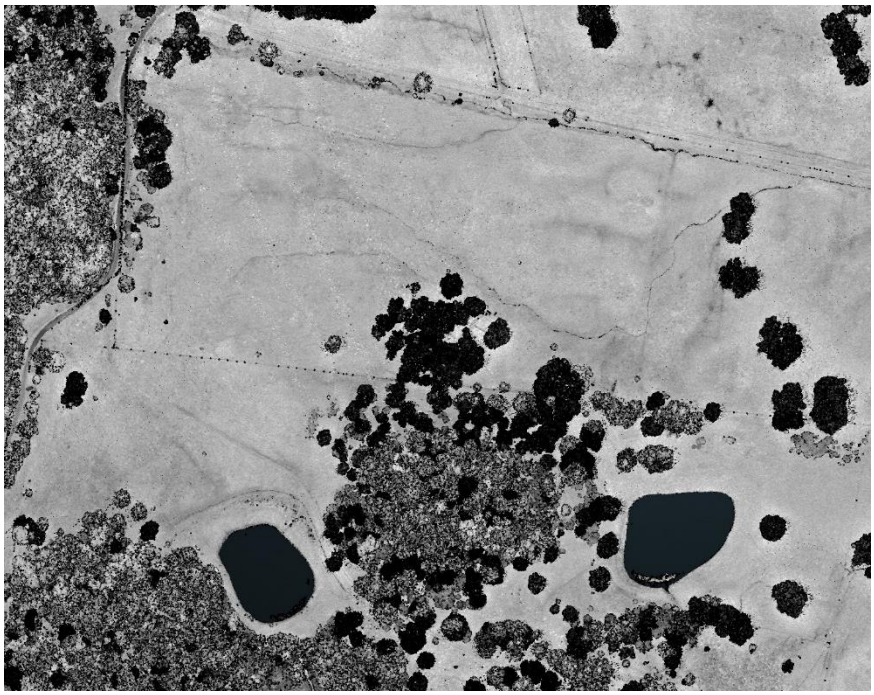


Open source and FAIR data methods are useful for this group because they are unlikely to purchase commercial geospatial licenses. In addition, the technology adoption lifecycle is likely to be both more variable and longer than users at agencies. The ability to manage legacy open-source software is incredibly important for this group. These users have a unique management relationship with the forests. Many are looking at hundreds to thousands of trees individually. Institutional land managers tend to think of Lidar derived inventories as competing with field inventories. The more accurate approach is to view lidar as producing a complementary product that increases the predictive power of the field inventory data. Adding basal area measurements to the lidar derived tree inventories dramatically increases the value of the canopy model. One of the biggest challenges communicating the benefits of airborne lidar is that the highest value results from data fusion with field inventories. This is necessary for integration with our existing forestry regulatory system, and it is important for calibrating relatively coarse regional forest mensuration models.

The Forest Inventory and Analysis program is a national cooperative forest inventory system with standardized plots and inventory procedures. The FIA datasets are critical for informing change over time. FIA was designed as a county scale tree census that samples approximately 1/10000 of the landscape every 5 to 10 years. In order to avoid a series of problems, the FIA site's locations are "fuzzed". There are very good reasons why this is done. However, this is a major barrier for calibrating lidar data.

Within our current operational environment there is an acute need for shared forest field inventory data to calibrate remotely sensed products of all kinds. This is a standard process in the commercial forestry carbon offset community however those landowners typically consider their own inventory data as a trade secret. Creating a mechanism for public interest forest managers and potentially small forest land managers to share inventory data in a scalable fashion that can be used to calibrate remote sensing data is going to be a critical need going forward.

The Future



In some ways the opportunity for the CaFLAC concept is improving. In early 2019 the Legislative Analysts Office recommended IN that report they identified. Over the last 4 years a coalition of people and organizations working in the forest resilience sector has responded to that critique by delivering technical solutions and building the capacity to use the spatial data infrastructure.

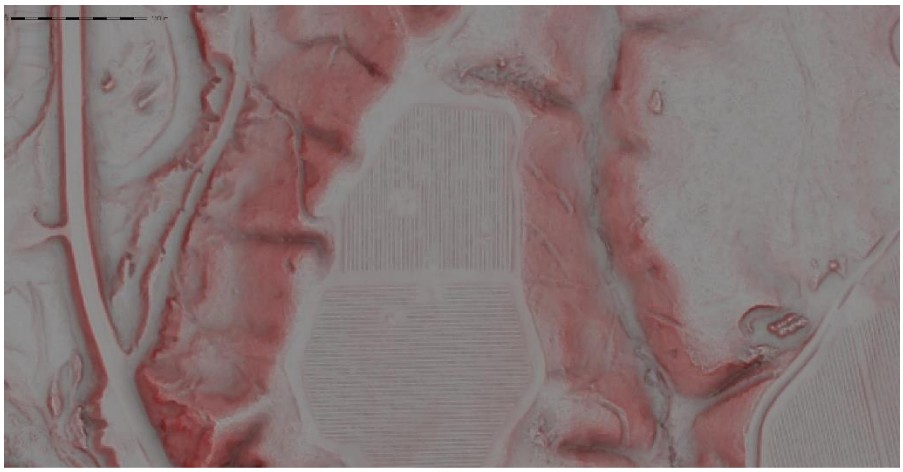
In 2021 the California Natural Resources Agency was given a onetime $25 million investment that funded the States share of the 8 USGS 3DEP collections in 2022 and 2023. From here on out public Lidar is available for almost every forestry project in California. These collections include the first repeat flights of 3DEP lidar and large areas of 2020 and 2021 fire footprints. These datasets are going to be critical for the post fire management of these landscapes. In addition, the Resources Agency is developing standardized lidar derivatives that will greatly facilitate analysis using traditional geospatial management systems.

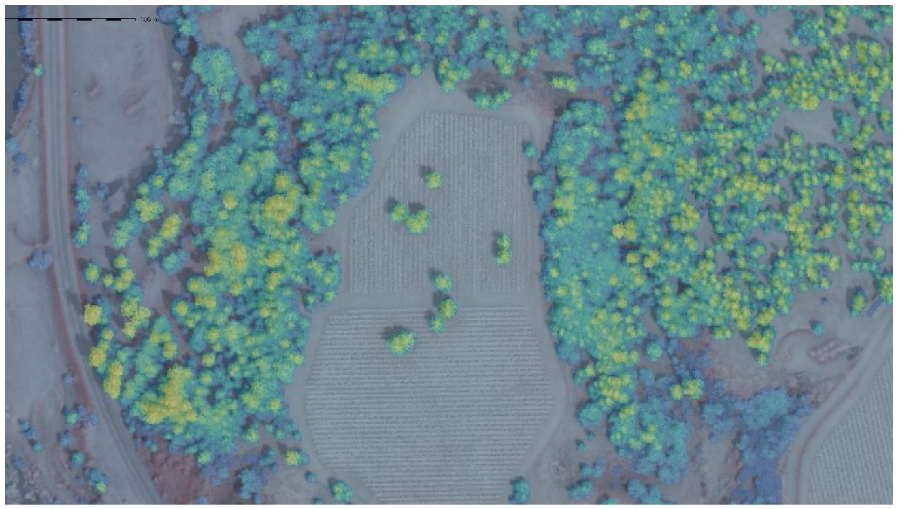
In addition, there are several emerging technical solutions that will greatly improve delivery of lidar derivative products. These include the Cloud Optimized Point Cloud standard, and the geoparquet vector format being adopted by the Overture Maps foundation. The development of digital twins continues.

While there are specialized skills needed to work with Lidar and point clouds there is also clear need for building geospatial capacity in general. One proposal in development is for a micro credential system to be hosted between the Watershed Center and Shasta College. This would serve as a professional geospatial development hub for the North State. There are several geospatial data systems in

development including the Climate and Wildfire Institutes regional toolkits, the USGS 3DHP program, and the Air Resources board's interagency implementation tracker are recent developments. In each case we are seeing a need for advanced workforce development to make these tools work for the network of users

There is an ongoing need to organize collaboratives to develop and deploy leading geospatial tools. WRTC and NV5 developed a prototype for the Upper Trinity with funding from the Sierra Nevada Conservancy. The 3DHP program needs the same kind of regional collaboratives that were required to get the USGS 3DEP collections flown.





There is also a growing need for tasked remote sensing to monitor forest treatment implementation. Drone based remote sensing is maturing quickly. There are now many competent contractors that can collect time sensitive data. We are seeing a need for integration of pretreatment, and as built tasked remote sensing products for project reporting. These need to be cost effective and meet certain quality standards so that these observations are easily interoperable.

The Yurok Tribe's Condor aviation program is a particularly important asset for Northern California's forestry and watershed management community. The Yurok tribe is invested in social, environmental, and economic well being of Northern California in unique way. Having state of the art remote sensing equipment permanently deployed in Northern California allows us to task project scale remote sensing at a dramatically lower cost than we would have from a national contractor. In the aftermath of the McKinney fire they mobilized a photogrammetry collection within 18 days of the fires ignition. Due to the severity of the emergency the Yurok tribe provided the photogrammetric point cloud before we had a mechanism to pay for it.

The continued need to develop advanced geospatial skills across the network of forest resilience organizations is very clear. There has been significant investment through State and federal funding mechanisms. In many cases the implementation partnerships are not well positioned to administer

these programs and are at a distinct disadvantage to the commercial technology providers. In order to get the most value out of these significant investments there is a tremendous need to build the internal capacity of the implementation partnerships.